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Evaluation of some bread wheat genotypes for heat tolerance under terminal heat stress conditions

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ABSTRACT

Terminal heat stress leads to significant yield reduction in wheat. Thus, the determination of heat tolerant genotypes is of major importance in wheat breeding program. The present study was conducted at Shandaweel agricultural research station, Sohag, Egypt during 2019/2020 and 2020/2021 growing seasons, to evaluate twelve bread wheat genotypes under normal sowing (20 November) and late sowing (30 December) dates, the experiment set up as a randomized complete block design with three replications. Results revealed that late sowing (terminal heat stress) had a significant adverse impact on agronomic, physiological traits and grain carbohydrate content. The genotype Shandaweel 2, followed by Giza 171 and Sids 14 performed better than other genotypes for grain yield under the normal sowing. On the other side, Shandaweel 2 outperformed the tested genotypes under the late sowing. Based on heat susceptibility index (HSI), the cultivars Sids 12, Misr 2, Sakha 95 and genotype Shandaweel 2 showed HSI<1 and they can be labeled as heat tolerant genotypes, while Sids 14, Misr 1, Giza 171 and Misr 3 showed HSI>1 and they can be considered as heat sensitive cultivars. GGE biplot analysis and ranking of genotypes revealed that the new line Shandaweel 2 was the an ideal genotype in terms of yielding ability and stability and it was suitable for planting under normal and late sowing conditions, while Giza 171 was suitable for planting under the normal sowing. The GYT biplot and superiority index showed that Shandaweel 2 and Giza 171 had the best traits profile.

Keywords: wheat, sowing dates, heat susceptibility index, GGE biplot

INTRODUCTION

Wheat is the main source for human food in the world as well as in Egypt. The wheat cultivated area in Egypt reached 1.44 million hectare in 2020/2021 growing season, with annual production of 9.38 million ton with an average yield of 6.52 t/ha (Economic Affairs Annual report, 2021). However, the total annual production of wheat in Egypt is still far below than the annual consumption, and the imports are increasing every year to face the growing population. Elevated air temperature during the grain filling period or post anthesis, which is known as terminal heat stress, is considered as the major environmental factor drastically reducing wheat production, especially with late sowing in Upper Egypt. Several researchers studied the impact of terminal heat stress on agronomic, physiological and grain quality traits in wheat. Gupta et al. (2015) reported that the terminal heat stress (≥32 °C) reduced starch content, grain quality, and grain weight which have a negative impact on grain yield. Subjected wheat to ambient temperature, more than 35 °C, for a short period of time caused significant loss in grain yield (Sharma et al., 2017). Delaying sowing of wheat, significantly reduced days to heading, days to maturity, plant height, yield and its components (Abd El-Rady and Koubisy, 2017) and decreased grain filling rate and grain filing duration (Aglan et al., 2020; Feltaous et al., 2020; Shenoda et al., 2021). Damage to cell membrane integrity and the primary photosynthetic process, as well as changes in lipid composition and protein denaturation can all be caused by high temperatures. (Wahid et al., 2007). Reduction in plant vigor is associated with the reduction in relative water content in crops under heat stress conditions (Arjenaki et al., 2012). The loss of chlorophyll in leaves occurs due to rapid breakdown of chlorophyll under heat stress (Jespersen et al., 2016). Wheat plants exposed to heat stress early in grain filling were found to have a high grain protein content (Castro et al., 2007). Consequently, development of heat tolerant cultivars is a major concern in wheat breeding programs. In the field, delaying the sowing date compared to normal sowing date under the same field conditions, is still a common procedure which proved to be an efficient tool for evaluation of large number of genotypes under heat stress in Egypt. The relative performance of yield traits in heat-stressed (late sowing) and non-stressed (optimum sowing) environments has been widely used to identify heat-tolerant wheat genotypes (Sharma et al., 2016). Based on that, Heat Susceptibility Index (HSI) is used as indicators of yield stability and a proxy for heat tolerance in wheat (Lobell et al., 2012). Keeping this in view, the present study was carried out to evaluate the performance of twelve Egyptian bread wheat genotypes under terminal heat stress (late sowing date) based on some agronomic and physiological traits to identify the heat tolerant genotypes for growing under such conditions.

MATERIALS AND METHODS

Experimental site

The field experiments of this study were conducted during the 2019/2020 and 2020/2021 wheat growing seasons at Shandaweel Agricultural Research Station, Sohag, Egypt. The geographical location is 31°42´E longitude, 26°33´N latitude and 61 m above the sea level, in Upper Egypt. The average annual rainfall and temperature are 1mm and 23.5 °C, respectively. The weather data were obtained from the Central Laboratory of Meteorology, Ministry of Agriculture, Egypt (Table 1).

The soil texture is a clay loam for 0-30 cm depth with low electrical conductivity (EC) of 0.5 and 0.6 ds/m and slightly alkaline (PH) of 7.4 and 7.8 in the first and second seasons, respectively. Soil available of N, P and K content were 52, 19 and 290 ppm in the first and 48, 11 and 265 ppm in the second season, respectively.

Experimental treatments and design

Ten bread wheat cultivars and two advanced lines were planted under normal and late sowing dates. Name, pedigree and selection history of these genotypes are shown in Table 2. The normal sowing date was on 20 November and the late sowing date (terminal heat stress) was on 30 December. Each sowing date in each season was considered as a separate experiment. The experimental design for each sowing date was a randomized complete block design (RCBD) with three replications. Each plot consists of 6 rows, spaced 20 cm and of 3.5 m long with a total area of 4.2 m^2. The seeding rate was 350 seed/m^2. All the wheat recommendation packages in Upper Egypt were applied.

Studied traits

The studied traits included days to heading (DH), days to maturity (DM), grain filling rate in kg/ha per day (GFR, equal to grain yield divided by number of days from anthesis to maturity), plant height in cm (PH), number of spikes/m^2 (SM), number of kernels/spike (KS), thousand kernel weight in gram (TKW), grain yield in t/ha(GY), membrane stability index was measured by conductivity meter (Century Instruments Chandigarh, India) at the mid-grain filling according to Sairam et al. (1997) equation: MSI% = 1- [(C1/C2)] x 100, where C1 and C2 are electric conductivity at 45 and 100 °C, respectively, leaf relative water content was measured at the mid-grain filling according to Pask et al. (2012) equation: RWC% = [FW – DW] / [TW – DW] × 100 where, FW= fresh leaf weight, DW= dry leaf weight and TW= turgid leaf weight, Leaf chlorophyll content (LCC) measured by a hand held chlorophyll meter (SPAD-502 Konica Minolta, osaka, Japan) and Grain protein content (PC) according to Lowry et al. (1951).Heat Susceptibility Index was calculated according to the formulae of Fisher and Maurer (1978): HSI = (1–yh/yp)/H. Where: yh = mean yield under heat conditions, yp= mean yield under normal conditions, H = heat stress intensity = 1-(yh of all genotypes/yp of all genotypes).

Table 1. The average data of monthly minimum and maximum temperature and Precipitation, during 2019/20 and 2020/21 growing seasons

		Month						
		November	December	January	February	March	April	May
Minimum temperature (°C)	2019/2020	15.73	9.26	6.52	9.17	14.06	17.40	22.58
	2020/2021	14.00	12.10	9.81	9.86	13.97	20.60	27.00
Maximum temperature (°C)	2019/2020	29.70	23.03	18.77	22.66	28.74	32.53	37.97
	2020/2021	25.07	24.45	23.00	24.25	29.52	34.20	39.68
Precipitation (mm)	2019/2020	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2020/2021	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 2. Name, pedigree and selection history of the twelve bread wheat genotypes

Name	Pedigree and selection history
Shandaweel 1	ITE/MO/4/NAC/TH.AC//3*PVN/3/MIRLO/BUC CMSS93B00567S-72Y-0l0M-010Y-010M-3Y-0M-0HTY-0SH
Line Shandaweel 2	QUAIU/5/FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ CMSS06B00109S-0Y-099ZTM-099NJ-099NJ-13WGY-0B-0SH
Sids 12	BUC//7C/ALD/5/MAYA74/ON//1160.147/3/BB/GLL/4/CHAT"S"/6/MAYA/VUL//CMH74A.630/4*SX SD7096-4SD-1SD-1SD-0SD
Sids 14	BOW"S"/VEE"S"//BOW"S"/TSI/3/BANI SEWEF 1 SD293-1SD-2SD-4SD-0SD
Misr 1	OASIS/SKAUZ//4*BCN/3/2*PASTOR CMSS00Y01881T-050M-030Y-030M-030WGY-33M-0Y-0S
Misr 2	SKAUZ/BAV92 CMSS96M03611S-1M-010SY-010M-010SY-8M-0Y-0S
Misr 3	ATTILA*2/PBW65*2/KACHU CMSS06Y00582T-099TOPM-099Y-099ZTM-099Y-099M-10WGY-0B-0EGY
Giza 171	SAKHA 93/GEMMEIZA 9 S.6-lGZ-4GZ-lGZ-2GZ-0S
Gemmiza 11	BOW"S"/ KVZ // 7C / SERI 82 /3/ GIZA 168 / SAKHA 61 CGM 7892 – 2GM-1GM-2GM-OGM
Gemmiza 12	OTUS/3/SARA/THB//VEE CMSS97Y00227S-5Y-010M-010Y-010M-2Y-1M-0Y-0GM
Sakha 95	PASTOR//SITE/MO/3/CHEN/ AEGILOPSSQUARROSA(TAUS)//BCN/4/WBLL1 CMSA01Y00158S-040POY-040M-030ZTM-040SY-26M-0Y-0SY-0S.
Line Sakha 1001	SIDS1/ATTILA//GOUMRIA-17 S.16498-042S-013S-21S-0S

Statistical analysis

Separate analysis of variance, combined analysis of variance across seasons and sowing dates (ANOVA) after testing the homogeneity of errors using Barttlet (1937) test and simple correlation coefficients among all studied traits were performed according to Gomez and Gomez (1984) using MSTATC statistical package. The means of sowing dates and genotypes were obtained and differences were assessed with LSD at 5% level of probability. Genotype by genotype-environment biplot (GGE biplot) technique of grain yield for the cultivars was performed for the four environmental conditions (two seasons×two sowing dates) according to Yan and Tinker (2006). The dataset was subjected to a novel approach of genotype× yield*trait analysis (GYT biplot) according to the procedure of Yan and Fregeau (2018). The GYT approach can be executed following few steps; Computing overall means and standard deviation for both seasons and sowing dates for all traits including grain yield, transforming the genotypes data table to yield*trait combinations (GYT) table by either multiply or dividing grain yield of each genotype with its respective parameter depending upon the breeding objectives. So, in the GYT table grain yield was divided by DH, DM, and PH with a notation of "/" as our objective of developing advance wheat lines, early maturing with short stature which could resist lodging. All the other yield components (GFR, SM, KS, TKW, MSI, RWC, LCC and PC) was multiplied (*) by grain yield as larger means of these traits were more desirable. Eventually, before the final evaluation of genotypes the GYT table was standardized to remove the differences in the measuring units of yield trait combinations according to following equation: **Pij=Tij-Tj /Sj**, Where: Pij is the standardized value of genotype i for trait or yield-trait combination j in the standardized table, Tij is the original value of genotype i for trait or yield-trait combination j in the GYT table, Tj is the mean across genotypes for trait or yield*trait combination j, and Sj is the standard deviation for trait or yield*trait combination j. This standardized dataset of GYT was then subjected to GYT biplot analysis and to calculate the mean superiority index (SI) value of each genotype. All biplot techniques and data visualization were performed using Genstat (19th Ed.) statistical software.

RESULTS

Season effect

Significant differences (*P*<0.01) were detected between the two growing seasons for all studied traits (Table 3). The highest mean values were observed for all traits in 2019/2020 season, except for grain protein content which was the highest in 2020/2021season.

Sowing date effect

Results in Table 3 showed significant effects (*P*<0.01) between normal and late sowing dates across the two sowing seasons for all studied traits. The normal sowing date recorded the highest mean values for all studied traits except grain protein content. The late sowing (terminal heat stress) significantly decreased days to heading by 12.98%, days to maturity by 15.91%, grain filling rate by 11.33%, plant height by 9.23%, number of spikes/m^2 by 23.02%, number of kernels/spike by 10.97%, thousand kernel weight by 17.37%, grain yield by 30.89%, membrane stability index by 8.68%, water relative content by 12.20% and leaf chlorophyll content by 10.24%, while significantly increased grain protein content by 8.43% as compared to normal sowing date.

Genotype effect

Combined across seasons and sowing dates, significant differences (*P*<0.01) between genotypes were detected for all studied traits (Table 3). Regarding number of days to heading and maturity, Sakha 1001 was the earliest genotype, while Sids 14 and Shandaweel 2 were the latest genotypes. The highest values of grain filling rate, plant height and number of spikes/m^2 were recorded with Shandaweel 2, while the lowest values were obtained with Sakah 1001. The greatest number of kernels/ spike were obtained by Misr 2, while the least were belonging to Giza 171 and Gemmiza 11. The maximum thousand kernels weight was showed from cultivar Giza 171, whereas the minimum value was recorded in cultivar Misr 2. Genotype

Shandaweel 2 produced the highest grain yield (6.63 t/ha), while genotype Sakha 1001 the lowest (4.58 t/ha). Membrane stability index ranged from 64.74% for Sids 14 to 80.32% for Shandaweel 2. In respect to relative water content, genotype Shandaweel 2 exhibited the highest value, while cultivar Shandaweel 1 recorded the lowest. Cultivar Sids 12 exhibited the highest value for leaf chlorophyll content (49.87 SPAD units), and cultivar Sids 14 the lowest (41.92 SPAD units). The highest value of grain protein content was obtained by cultivar Giza 171, while the lowest was recorded by genotype Sakha 1001.

Table 3. Endophytic isolates obtained from two soybean cultivars

Item	Trait											
	DH	DM	GFR	PH	SM	KS	TKW	GY	MSI	RWC	LCC	PC
Seasons												
2019/2020	87.4	132.2	158.7	103.9	350.2	60.6	49.2	5.99	73.79	78.81	45.60	12.52
2020/2021	84.1	127.0	154.5	96.4	310.3	56.6	46.5	5.56	69.92	74.56	42.76	12.95
F test	**	**	**	**	**	**	**	**	**	**	**	**
Sowing dates												
Normal	91.7	140.8	166.0	105.0	373.2	62.0	52.4	6.83	75.11	81.66	46.57	12.22
Late	79.8	118.4	147.2	95.3	287.3	55.2	43.3	4.72	68.59	71.70	41.80	13.25
Reduction (%)	-12.98	-15.91	-11.33	-9.23	-23.02	-10.97	-17.37	-30.89	-8.68	-12.20	-10.24	8.43
F test	**	**	**	**	**	**	**	**	**	**	**	**
Genotypes												
Shand 1	85.6	130.3	151.5	97.6	344.4	60.4	45.1	5.72	66.58	73.68	43.11	13.18
Shand 2	91.7	133.8	189.2	113.8	355.5	61.4	49.1	6.63	80.32	80.16	45.58	13.16
Sids 12	81.5	125.3	153.9	91.5	320.6	61.2	47.9	5.68	73.34	77.45	49.87	11.87
Sids 14	92.0	135.5	160.2	109.7	341.5	56.4	48.7	5.96	64.74	77.79	41.92	12.17
Misr 1	85.1	128.3	151.9	93.8	325.8	58.9	47.1	5.57	67.88	77.63	42.93	13.75
Misr 2	89.6	133.1	158.4	105.5	331.3	64.0	44.4	5.86	73.35	75.13	43.60	12.89
Misr 3	85.7	131.0	153.3	96.8	326.8	59.1	47.8	5.97	76.19	76.69	43.95	12.93
Giza 171	87.9	132.1	173.2	103.3	341.8	55.4	52.8	6.33	74.18	79.14	45.06	13.95
Gemm 11	83.2	127.8	145.9	101.1	316.8	55.8	50.6	5.51	74.96	73.85	43.29	13.02
Gemm 12	84.1	127.2	156.2	101.6	319.8	57.1	48.5	5.52	67.95	74.57	42.43	12.50
Sakha 95	87.5	130.4	165.3	105.3	338.0	57.2	47.0	5.99	71.02	78.05	46.42	11.76
Sakha1001	75.6	120.4	120.2	81.7	300.4	56.4	44.8	4.58	71.70	76.04	42.02	11.61
F test	**	**	**	**	**	**	**	**	**	**	**	**
$LSD_{0.05}$	0.93	1.35	6.20	2.24	11.20	1.99	1.21	0.24	1.50	1.47	0.95	0.54

DH: number of days to heading, DM: number of days to maturity, GFR: grain filling rate (kg/ha per day), PH: plant height (cm), SM: number of spikes/m^2, KS: number of kernels/spike, TKW: thousand kernel weight (g), GY: grain yield (t/ha), MSI: membrane stability index (%), RWC: relative water content (%), LCC: leaf chlorophyll content and PC: grain protein content (%).*and ** refer to $P<0.05$ and $P<0.01$, respectively

Interaction between season and sowing date

The results in Table 4 and 5 indicated that the interaction between seasons and sowing dates was significant ($P<0.05$; $P<0.01$) in all studied traits, except for number of kernels/spike. The highest values for all traits were obtained by normal sowing date in the first season, except for grain protein content, which gave the highest value under late sowing in the second season. In contrast, the lowest values for all traits were exhibited under late sowing in the second season, except for grain filling rate and grain protein content.

Interaction between season and genotype

The performance of genotypes in the two seasons are presented in Table 6. Genotypes differed significantly for all studied traits, except for days to maturity, grain yield, relative water content and grain protein content. The highest values of DH, GFR, PH and SM were obtained by genotype Shandaweel 2 in the first season, while the lowest values were recorded by genotype Sakha 1001 in the second season. Misr 2 produced the greatest value of KS in the first, whereas Gemmiza 11 had the least value in the second season. The maximum TKW was recorded by Giza 171 and the minimum by Misr 2 in the 2020/2021 season. The greatest value of MSI was found for genotype Shandaweel 2 in the first, while the least value was found for cultivar Sids 14 in the second season. Cultivar Sids 12 exhibited the highest LCC in the first, while genotype Sakha 1001 exhibited the lowest LCC in the second season.

Table 4. Interaction between season and sowing date for: number of days to heading (DH), number of days to maturity (DM), grain filling rate (GFR), plant height (PH), number of spikes/m^2 (SM) and number of kernels/spike (KS)

Season	Sowing date	Trait					
		DH	DM	GFR	PH	SM	KS
2019/2020	Normal	94.3	142.7	176.4	108.2	403.2	63.7
	Late	80.6	121.6	141.0	99.6	297.2	57.5
2020/2021	Normal	89.1	138.8	155.6	101.8	343.2	60.3
	Late	79.1	115.2	153.4	90.9	277.4	53.0
	F test	**	**	**	*	**	ns
	LSD $_{0.05}$	0.75	1.08	4.96	1.8	8.98	----

ns, *and ** refer to non significant, $P<0.05$ and $P<0.01$, respectively

Table 5. Interaction between season and sowing date for: thousand kernel weight (TKW), grain yield (GY), membrane stability index (MSI), relative water content (RWC), leaf chlorophyll content (LCC) and grain protein content (PC)

Season	Sowing date	Trait					
		TKW	GY	MSI	RWC	LCC	PC
2019/2020	Normal	54.1	7.10	77.53	83.23	48.28	12.12
	Late	44.2	4.87	70.04	74.39	42.93	12.92
2020/2021	Normal	50.6	6.56	72.69	80.10	44.85	12.31
	Late	42.3	4.57	67.15	69.01	40.67	13.58
	F test	**	*	**	**	**	*
	LSD $_{0.05}$	0.97	0.19	1.20	1.18	0.76	0.43

*and ** refer to $P<0.05$ and $P<0.01$, respectively

Table 6. Interaction between season and genotype on studied traits

Traits	DH	DM	GFR	PH	SM	KS	TKW	GY	MSI	RWC	LCC	PC
Genotypes						2019/2020						
Shand 1	87.7	133.2	156.3	100.3	374.5	62.5	46.9	5.92	67.28	75.22	44.78	12.85
Shand 2	94.3	136.5	200.4	119.8	385.0	64.8	50.6	7.05	82.49	82.65	47.77	12.90
Sids 12	82.8	127.8	153.8	94.3	334.8	65.7	49.5	5.89	76.36	80.05	50.75	11.79
Sids 14	93.3	137.8	158.6	115.2	365.3	58.1	50.1	6.07	66.74	80.87	43.35	11.96
Misr 1	86.7	130.8	152.5	98.2	343.7	60.0	49.0	5.74	69.42	80.17	44.15	13.69
Misr 2	91.2	135.3	156.6	108.8	346.0	68.3	46.4	5.95	74.89	77.43	44.28	12.69
Misr 3	87.3	133.7	152.1	101.3	346.5	59.5	49.6	6.05	78.42	78.32	45.55	12.69
Giza 171	88.8	134.7	177.4	107.2	365.0	56.5	52.3	6.63	76.76	81.06	47.28	13.96
Gemm 11	84.7	130.7	147.2	104.7	334.7	58.2	51.2	5.80	78.24	76.28	44.02	13.13
Gemm 12	85.7	129.5	160.0	102.3	336.7	58.6	50.0	5.79	68.93	76.32	43.05	12.14
Sakha 95	88.7	132.7	166.7	110.8	356.5	58.4	48.5	6.16	72.47	79.74	48.59	11.39
Sakha 1001	78.2	123.2	122.5	84.0	313.5	56.6	46.1	4.77	73.43	77.60	43.69	11.09
Genotypes						2020/2021						
Shand 1	83.5	127.3	146.6	94.8	314.3	58.3	43.3	5.51	65.89	72.14	41.43	13.52
Shand 2	89.0	131.2	177.9	107.8	326.0	57.9	47.7	6.20	78.16	77.68	43.40	13.43
Sids 12	80.2	122.8	154.0	88.7	306.3	56.7	46.4	5.46	70.31	74.85	49.00	11.96
Sids 14	90.7	133.2	161.8	104.2	317.7	54.8	47.3	5.84	62.74	74.72	40.50	12.38
Misr 1	83.5	125.7	151.4	89.5	307.8	57.7	45.2	5.41	66.35	75.09	41.70	13.82
Misr 2	88.0	130.8	160.3	102.2	316.7	59.8	42.4	5.76	71.81	72.83	42.91	13.08
Misr 3	84.0	128.3	154.5	92.2	307.2	58.7	46.0	5.88	73.96	75.07	42.35	13.18
Giza 171	87.0	129.5	169.0	99.5	318.5	54.4	53.3	6.02	71.61	77.23	42.83	13.95
Gemm 11	81.7	124.8	144.6	97.5	299.0	53.3	49.9	5.23	71.68	71.43	42.56	12.91
Gemm12	82.5	124.8	152.3	100.8	303.0	55.7	47.1	5.24	66.97	72.82	41.81	12.86
Sakha 95	86.3	128.2	163.9	99.8	319.5	56.0	45.5	5.81	69.57	76.37	44.26	12.14
Sakha 1001	73.0	117.7	117.9	79.3	287.3	56.2	43.6	4.40	69.98	74.47	40.36	12.14
Ftest	**	ns	**	**	*	**	**	ns	*	ns	**	ns
$LSD_{0.05}$	1.32	------	8.76	3.17	15.84	2.81	1.71	------	2.11	------	1.34	------

DH: number of days to heading, DM: number of days to maturity, GFR: grain filling rate (kg/ha per day), PH: plant height (cm), SM: number of spikes/m^2, KS: number of kernels/spike, TKW: thousand kernel weight (g), GY: grain yield (t/ha), MSI: membrane stability index (%), RWC: relative water content (%), LCC: leaf chlorophyll content and PC: grain protein content (%). ns, *and ** refer to non significant, *P*<0.05 and *P*<0.01, respectively

Interaction between sowing date and genotype

Results in Table 7 illustrate significant effects ($P<0.05$; $P<0.01$) between sowing dates and genotypes across the two seasons for all studied traits, except plant height. The highest values of all genotypes for all traits were under normal sowing date, except for grain protein content. Regarding number of days to heading and maturity, the genotype Sakha 1001 was the earliest genotype, while cultivar Sids 14 was the latest genotypes in both sowing dates. For grain filling rate, genotype Shandaweel 2 exhibited the highest values under normal and late sowing dates, (199.3 and 179.0 kg/ha per day respectively), while the lowest values were for genotype Sakha 1001(124.2 and 116.1 kg/ha per day respectively). The highest number of spikes/m^2 were obtained by cultivars Shandaweel 1, Giza 171 and genotype Shandaweel 2 under normal sowing date and by Shandaweel 2, Sakh 95 and Misr 2 under late sowing dates. While, the lowest number of spikes/m^2 was found by genotype Sakha 1001 under both sowing dates, but it was in par with Sids 12 and Gemmiza 12 under normal planting and with Gemmiza 11 under late planting. The greatest values for KS were recorded by cultivar Misr 2 under both sowing dates, while the lowest values were recorded by cultivar Giza 171 under normal sowing and by genotype Sakha 1001 under late sowing. The Maximum values for TKW were obtained by Giza 171 under both sowing date, Sids 14 and Gemmiza 11 under late sowing date. In contrast, cultivars Misr 2, Shandaweel 1 and genotype Sakha 1001 gave the lowest values for TKW under both sowing dates. Concerning grain yield, Shandaweel 2, Giza 171 and Sids 14 produced the highest grain yield (7.80, 7.78 and 7.49 t/ha respectively) under the normal sowing date. Moreover, genotype Shandaweel 2 gave the highest grain yield (5.45 t/ha) under late sowing date, significantly higher than other genotypes. In contrast, the lowest values of grain yield (5.27 and 3.90 t/ha) were recorded by genotype Sakha 1001 under normal and late sowing dates, respectively. The highest values of MSI were found for Shandaweel 2, under normal and late sowing dates (83.64 and 77.00% respectively), while the lowest values were obtained by cultivar Sids 14 under normal and late sowing date (69.39 and 60.09% respectively).

The greatest values of RWC were recorded by Giza 171, Shandaweel 2 and Sids 14 under normal sowing date and by Shandaweel 2, Sids 12 and Sakha 95 under late sowing date. On the other hand, cultivars Gemmiza 11, Shandaweel 1, Misr 2, Gemmiza 12 and genotype Sakha 1001 gave the minimum values of RWC under normal sowing date, while under late sowing date, Shandaweel 1,Gemmiza 11 and Gemmiza 12 gave the lowest values. Cultivar Sids 12 exhibited the highest values for LCC under normal and late sowing dates (52.05 and 47.70 SPAD units, respectively). In contrast, the lowest values for LCC units were recorded by cultivars Gemmiza 12 and Sids 14 under normal and late sowing dates (44.33 and 39.00 SPAD respectively). The maximum grain protein content under normal and late sowing dates was found for cultivar Giza 171 (13.54 and 14.37% respectively), while the minimum grain protein content was found for genotype Sakha 1001 under normal and late sowing dates (11.03 and 12.20% respectively).

Interaction between season, sowing date and genotype

Results in Table 8 and 9 showed that the interaction effect between the three factors was significant for DH, GFR, PH, SM, TKW, GY and LCC ($P<0.05$) and for KS ($P<0.01$). The earliest genotype was Sakha 1001 under both seasons and sowing dates, while the latest genotype was cultivar Sids 14 in the second season under both sowing dates and in the first season under normal sowing and genotype Shandaweel 2 in the first season under late sowing. The maximum GFR was observed by genotype Shandaweel 2 in season 2019/2020 under both sowing dates, by Sids 12 under normal sowing and Shandaweel 2 under late sowing in season 2020/2021. The minimum GRF was observed by genotype Sakha 1001 under both seasons and sowing dates. Shandaweel 2 was the tallest genotype, while Sakah 1001 was the shortest genotype under both seasons and sowing dates. The highest values of SM were recorded by Shandaweel 1 in the first season and Giza 171 in the second season under normal sowing, while under late sowing Shandaweel 2 gave the highest values in both seasons. Genotype Sakha 1001 recorded

Table 7. Interaction between sowing dates and genotypes on studied traits

Traits	DH	DM	GFR	PH	SM	KS	TKW	GY	MSI	RWC	LCC	PC
Genotypes						Normal sowing						
Shand 1	91.2	141.0	157.8	103.2	405.1	65.82	49.67	6.69	70.50	79.08	45.83	12.89
Shand 2	97.7	145.5	199.3	119.2	396.5	66.26	53.66	7.80	83.64	84.85	47.63	12.69
Sids 12	87.2	136.0	156.1	97.3	350.7	66.91	52.62	6.41	75.36	81.39	52.05	11.21
Sids 14	98.3	147.7	179.3	115.2	386.8	59.02	52.65	7.49	69.39	84.05	44.85	11.30
Misr 1	90.5	139.5	171.7	100.2	367.3	60.55	50.37	6.91	71.14	82.98	45.20	13.39
Misr 2	96.8	145.2	163.6	110.3	362.8	69.46	48.66	6.73	75.32	79.15	45.06	12.55
Misr 3	92.0	142.5	166.7	100.8	374.2	61.30	51.40	7.10	80.50	82.21	46.32	12.75
Giza 171	93.3	143.3	188.3	107.5	397.2	55.94	59.32	7.78	77.05	85.45	48.90	13.54
Gemm 11	88.8	139.2	150.2	104.7	362.5	57.37	55.68	6.43	78.39	78.85	45.02	11.69
Gemm 12	89.8	138.2	157.8	106.2	357.5	59.32	54.55	6.34	70.50	79.04	44.33	12.22
Sakha 95	94.5	141.5	176.9	109.8	374.8	59.96	51.20	6.97	73.98	82.64	48.72	11.33
Sakha 1001	80.7	129.8	124.3	85.5	342.8	61.85	48.63	5.27	75.57	80.29	44.87	11.03
Genotypes						Late sowing						
Shand 1	80.0	119.5	145.2	92.0	283.7	55.00	40.48	4.74	62.67	68.28	40.38	13.48
Shand 2	85.7	122.2	179.0	108.5	314.5	56.49	44.60	5.45	77.00	75.48	43.53	13.63
Sids 12	75.8	114.7	151.7	85.7	290.5	55.44	43.27	4.94	71.31	73.50	47.70	12.54
Sids 14	85.7	123.3	141.1	104.2	296.2	53.88	44.78	4.42	60.09	71.53	39.00	13.03
Misr 1	79.7	117.0	132.2	87.5	284.2	57.17	43.85	4.23	64.63	72.28	40.65	14.11
Misr 2	82.3	121.0	153.7	100.7	299.8	58.59	40.10	4.99	71.39	71.10	42.13	13.23
Misr 3	79.3	119.5	139.9	92.7	279.5	56.90	44.12	4.83	71.89	71.18	41.58	13.11
Giza 171	82.5	120.8	158.0	99.2	286.3	54.93	46.35	4.87	71.32	72.84	41.22	14.37
Gemm 11	77.5	116.3	141.6	97.5	271.2	54.16	45.45	4.60	71.53	68.86	41.56	14.35
Gemm12	78.3	116.2	154.6	97.0	282.2	54.97	42.50	4.69	65.40	70.10	40.53	12.79
Sakha 95	80.5	119.3	153.6	100.8	301.2	54.47	42.85	5.00	68.05	73.47	44.12	12.20
Sakha 1001	70.5	111.0	116.1	77.8	258.0	50.95	41.02	3.90	67.84	71.78	39.18	12.20
Ftest	**	*	**	ns	**	**	**	**	**	*	**	**
$LSD_{0.05}$	1.32	1.91	8.76	-----	15.84	2.81	1.71	0.34	2.11	2.08	1.34	0.76

DH: number of days to heading, DM: number of days to maturity, GFR: grain filling rate (kg/ha per day), PH: plant height (cm), SM: number of spikes/m^2, KS: number of kernels/spike, TKW: thousand kernel weight (g), GY: grain yield (t/ha), MSI: membrane stability index (%), RWC: relative water content (%), LCC: leaf chlorophyll content. and PC: grain protein content (%).ns, *and ** refer to non significant, $P<0.05$ and $P<0.01$, respectively

Table 8. Interaction between season, sowing date and genotype for days to heading (DH), days to maturity (DM), grain filling rate (GFR), plant height (PH), number of spikes/m² (SM) and number of kernels/spike (KS)

Traits	DH		DM		GFR		PH		SM		KS	
Sowing date	N	L	N	L	N	L	N	L	N	L	N	L
Genotypes	2019/2020											
Shand 1	93.3	82.0	143.0	123.3	165.8	146.9	105.7	95.0	456.3	292.7	68.4	56.5
Shand 2	100.3	88.3	147.0	126.0	224.0	176.9	125.0	114.7	444.3	325.7	70.5	59.2
Sids 12	89.7	76.0	138.0	117.7	167.3	140.3	100.7	88.0	371.3	298.3	72.8	58.6
Sids 14	100.7	86.0	149.0	126.7	183.3	133.8	120.3	110.0	423.7	307.0	59.8	56.3
Misr 1	93.7	79.7	141.3	120.3	178.6	126.3	104.7	91.7	391.3	296.0	60.7	59.3
Misr 2	99.0	83.3	147.0	123.7	167.2	146.0	113.0	104.7	385.0	307.0	75.2	61.3
Misr 3	94.7	80.0	145.0	122.3	173.0	131.2	105.0	97.7	402.3	290.7	60.8	58.3
Giza 171	95.3	82.3	145.3	124.0	207.0	147.7	108.3	106.0	435.3	294.7	57.4	55.5
Gemm 11	91.3	78.0	141.3	120.0	158.9	135.6	106.0	103.3	387.0	282.3	58.7	57.7
Gemm 12	92.7	78.7	140.0	119.0	170.3	149.8	107.3	97.3	378.3	295.0	59.6	57.6
Sakha 95	97.0	80.3	143.3	122.0	187.1	146.3	114.0	107.7	402.3	310.7	59.9	56.9
Sakha 1001	84.3	72.0	132.3	114.0	134.0	111.0	88.3	79.7	361.0	266.0	60.6	52.6
Genotypes	2020/2021											
Shand 1	89.0	78.0	139.0	115.7	149.7	143.5	100.7	89.0	354.0	274.7	63.2	53.5
Shand 2	95.0	83.0	144.0	118.3	174.6	181.1	113.3	102.3	348.7	303.3	62.0	53.8
Sids 12	84.7	75.7	134.0	111.7	145.0	163.0	94.0	83.3	330.0	282.7	61.0	52.3
Sids 14	96.0	85.3	146.3	120.0	175.3	148.3	110.0	98.3	350.0	285.3	58.2	51.5
Misr 1	87.3	79.7	137.7	113.7	164.7	138.0	95.7	83.3	343.3	272.3	60.4	55.0
Misr 2	94.7	81.3	143.3	118.3	160.0	160.5	107.7	96.7	340.7	292.7	63.7	55.9
Misr 3	89.3	78.7	140.0	116.7	160.4	148.6	96.7	87.7	346.0	268.3	61.8	55.5
Giza 171	91.3	82.7	141.3	117.7	169.5	168.4	106.7	92.3	359.0	278.0	54.5	54.3
Gemm 11	86.3	77.0	137.0	112.7	141.5	147.7	103.3	91.7	338.0	260.0	56.0	50.6
Gemm12	87.0	78.0	136.3	113.3	145.3	159.4	105.0	94.0	336.7	269.3	59.1	52.4
Sakha 95	92.0	80.7	139.7	116.7	166.9	160.9	105.7	96.7	347.3	291.7	60.0	52.0
Sakha 1001	77.0	69.0	127.3	108.0	114.6	121.2	82.7	76.0	324.7	250.0	63.1	49.3
Ftest	*		ns		*		*		*		**	
$LSD_{0.05}$	1.86		------		12.39		4.48		22.40		3.97	

ns, *and ** refer to non significant, *P*<0.05 and *P*<0.01, respectively. N = normal and L = late sowing

Table 9. Interaction between season, sowing date and genotype for thousand kernel weight (TKW), grain yield (GY), membrane stability index (MSI), relative water content (RWC), leaf chlorophyll content (LCC) and grain protein content (PC)

Traits	TKW		GY		MSI		RWC		LCC		PC	
Sowing date	N	L	N	L	N	L	N	L	N	L	N	L
Genotypes	2019/2020											
Shand 1	52.4	41.3	6.91	4.94	71.52	63.04	80.15	70.28	47.80	41.77	12.79	12.90
Shand 2	55.1	46.0	8.50	5.60	86.45	78.52	86.73	78.58	50.47	45.07	12.63	13.16
Sids 12	54.4	44.5	6.79	5.00	79.16	73.55	83.49	76.60	53.63	47.87	11.22	12.35
Sids 14	54.6	45.7	7.50	4.64	71.92	61.57	86.60	75.13	46.70	40.00	11.15	12.76
Misr 1	53.4	44.7	7.01	4.46	72.89	65.95	84.98	75.36	46.20	42.10	13.53	13.84
Misr 2	52.1	40.7	6.85	5.06	76.56	73.23	80.15	74.70	45.30	43.27	12.30	13.08
Misr 3	53.8	45.3	7.20	4.90	83.53	73.30	83.46	73.18	48.13	42.97	12.65	12.72
Giza 171	58.0	46.7	8.35	4.92	80.50	73.02	86.78	75.34	50.87	43.70	13.58	14.33
Gemm 11	56.3	46.2	6.73	4.88	82.14	74.34	81.07	71.48	46.03	42.00	11.86	14.41
Gemm 12	56.0	44.0	6.68	4.89	72.03	65.83	79.87	72.77	45.07	41.03	12.01	12.27
Sakha 95	53.1	44.0	7.16	5.17	75.82	69.11	83.51	75.97	51.30	45.87	11.08	11.70
Sakha 1001	50.5	41.7	5.54	4.00	77.86	69.00	81.92	73.28	47.87	39.50	10.69	11.49
Genotypes	2020/2021											
Shand 1	46.9	39.6	6.48	4.54	69.48	62.29	78.00	66.28	43.87	39.00	12.98	14.05
Shand 2	52.2	43.2	7.10	5.30	80.83	75.48	82.98	72.38	44.80	42.00	12.75	14.10
Sids 12	50.8	42.0	6.04	4.89	71.56	69.07	79.29	70.40	50.46	47.53	11.20	12.72
Sids 14	50.7	43.9	7.48	4.20	66.86	58.62	81.50	67.93	43.00	38.00	11.45	13.30
Misr 1	47.3	43.0	6.81	4.00	69.38	63.31	80.98	69.21	44.20	39.20	13.26	14.37
Misr 2	45.2	39.5	6.61	4.92	74.07	69.54	78.15	67.50	44.82	41.00	12.80	13.37
Misr 3	49.0	42.9	7.00	4.76	77.46	70.47	80.96	69.18	44.50	40.20	12.85	13.50
Giza 171	60.6	46.0	7.22	4.82	73.60	69.61	84.12	70.34	46.93	38.73	13.50	14.40
Gemm 11	55.0	44.7	6.13	4.32	74.63	68.72	76.62	66.23	44.00	41.11	11.52	14.30
Gemm12	53.1	41.0	6.00	4.48	68.96	64.97	78.21	67.44	43.59	40.03	12.42	13.30
Sakha 95	49.3	41.7	6.79	4.83	72.14	67.00	81.76	70.97	46.15	42.37	11.57	12.70
Sakha 1001	46.8	40.4	5.00	3.80	73.28	66.68	78.67	70.28	41.87	38.85	11.38	12.90
Ftest	*		*		ns		ns		*		ns	
$LSD_{0.05}$	2.42		0.48		-----		-----		1.90		-----	

ns, *and ** and refer to non significant, *P*<0.05 and *P*<0.01, respectively. N = normal sowing and L = late sowing the lowest values of SM under both seasons and sowing dates. Cultivar Misr 2 had the highest values of KS under both seasons and sowing dates, while the lowest values were observed by cultivar Giza171 under normal sowing and genotype Sakha 1001 under late sowing in both seasons. Cultivar Giza 171 had the highest values of TKW under both seasons and sowing dates, while the lowest values were observed by genotype Sakha 1001 under normal sowing and Misr 2 under late sowing in both seasons. The highest grain yield was produced by Shandaweel 2 under both sowing dates in season 2019/2020 and by Sids 14 and Shandaweel 2 under normal and late sowing dates in season 2020/2021. In contrast, the lowest grain yield produced by Sakha 1001 under both season and sowing dates. The highest values for LCC exhibited by cultivar Sids 12 under both seasons and sowing dates, while the lowest value was recorded by Gemmiza 12 and Sakha 1001 under normal sowing and by Sakha 1001 and Sids 14 under late sowing in the first and second seasons, respectively.

Table 10. Mean of grain yield under normal and late sowing date over the two growing seasons, and heat susceptibility index (HSI) and yield reduction ratio (YR%)

Genotype	Grain yield (t/ha)		HSI	YR%
	Normal	Late		
Shandaweel 1	6.69	4.74	0.95	29.15
Shandaweel 2	7.80	5.45	0.98	30.13
Sids 12	6.41	4.94	0.74	22.93
Sids 14	7.49	4.42	1.33	40.99
Misr 1	6.91	4.23	1.26	38.78
Misr 2	6.73	4.99	0.84	25.85
Misr 3	7.10	4.83	1.04	31.97
Giza 171	7.78	4.87	1.21	37.40
Gemmiza 11	6.43	4.60	0.92	28.46
Gemmiza 12	6.34	4.69	0.84	26.03
Sakha 95	6.97	5.00	0.92	28.26
Sakha 1001	5.27	3.90	0.84	26.00

Heat susceptibility index (HSI)

The HSI and yield reduction ratio (YR) values among genotypes ranged from 0.74 and 22.93% for Sids 12 to 1.33 and 40.99% for Sids 14 (Table 10). The genotypes Sids 12, Misr 2, Gemmiza 12, Sakha 1001, Gemmiza 11, Shaka 95, Shandaweel 1 and Shandaweel 2 exhibited HSI values less than unit (HSI<1). Meanwhile, the cultivars Sids 14, Misr 1, Giza 171 and Misr 3 gave values of HSI higher than unit (HSI>1).

Correlation among traits

Under normal sowing date, the simple correlation coefficient (Table 11) was positive and significant (P<0.01) between grain yield and: DH, DM, GFR, PH, SM and RWC. On the other hand, under late sowing date the correlation coefficient was positive and significant (P<0.05) between grain yield and: DH, DM, GFR, PH, SM, MSI and LCC and it was positive and insignificant between grain yield and KS, TKW, RWC and PC.

Genotype by genotype environment biplot (GGE biplot)

GGE biplot analysis and ranking of genotypes was performed to detect the ideal or desirable genotypes (Figure 1).The biplot explained 95.41% of the total variation observed, of which 81.46% was explained by the first principal component, while the second principal component explained 13.95%. In general, Shandaweel 2 was the desirable genotype, while Sakah 1001 was the undesirable genotype. Identification of high yield and stable genotypes across environments was done by so-called the average environment coordinates (AEC) method (Yan and Tinker 2006). The average environment is defined by the average values of PC1 and PC2 for the all environments and it is presented with a circle. The average ordinate environment (AOE) defined by the line which is perpendicular to the average environment axis (AEA) line and pass through the origin. The genotypes on the left side of the ordinate had lower yield than mean yield but the genotypes on the right side of the ordinate had higher yield than mean yield across environments.

Table 11. Correlation coefficient among the studied traits under normal (above diagonal) and late (below diagonal) sowing dates

Trait	DH	DM	GFR	PH	SM	KS	TKW	MSI	RWC	LCC	PC	GY
DH		0.98**	0.85**	0.94**	0.66*	0.11	0.17	0.07	0.46	0.01	0.33	0.86**
DM	0.97**		0.83**	0.90**	0.71**	0.43	0.23	0.09	0.45	-0.03	0.39	0.88**
GFR	0.68*	0.60*		0.84**	0.72**	-0.07	0.44	0.24	0.77**	0.30	0.49	0.97**
PH	0.89**	0.86**	0.77**		0.63*	0.03	0.35	0.12	0.40	0.02	0.24	0.81**
SM	0.82**	0.76**	0.82**	0.77**		-0.06	0.30	0.07	0.49	0.08	0.55	0.79**
KS	0.53	0.51	0.48	0.37	0.57		-0.62*	0.14	-0.28	0.18	-0.02	-0.13
TKW	0.36	0.29	0.26	0.37	0.12	-0.02		0.25	0.40	0.29	0.24	0.48
MSI	0.03	0.01	0.51	0.20	0.24	0.31	0.25		0.27	0.31	0.13	0.24
RWC	0.26	0.17	0.45	0.21	0.57	0.13	0.31	0.49		0.41	0.26	0.75**
LCC	-0.02	-0.06	0.50	0.05	0.45	0.32	0.07	0.56	0.52		-0.10	0.25
PC	0.39	0.34	0.20	0.30	0.03	0.36	0.54	0.17	-0.18	-0.21		0.53
GY	0.59*	0.58*	0.93**	0.68*	0.79**	0.57	0.16	0.61*	0.40	0.64*	0.11	

DH: number of days to heading, DM: number of days to maturity, GFR: grain filling rate (kg/ha per day), PH: plant height (cm), SM: number of spikes/m^2, KS: number of kernels/spike, TKW: thousand kernel weight (g), GY: grain yield (t/ha), MSI: membrane stability index (%), RWC: relative water content (%), LCC: leaf chlorophyll content and PC: grain protein content (%). *and ** refer to $P<0.05$ and $P<0.01$, respectively

Thus, Figure 1 showed that Shandaweel 2, Giza 171, Sakh 95, Misr 3, Mis 2 and Sids 14 had yield higher than the grand mean, while Shandaweel 1, Sids12, Misr 1, Gemmiza 11, Gemmiza 12 and Sakha 1001 had yield less than grand mean. Stability of the genotypes depend on their distance from the AE abscissa. Genotypes closer to abscissa are more stable than others. Consequently, Shandaweel 2, Giza 171, Misr 2, Misr 3 and Sakha 95 were the most stable genotypes. The use of the polygon view of the "which-won-where" biplot is a key component of the GGE, which helps to visualize the interaction patterns between genotypes and environments, to show the presence of crossover GEI, mega-environment differentiation and specific adaptation (Yan and Tanker, 2006).

"Which-Won–Where" polygon (Figure 2) showed that there are two mega environments; first mega environment (ME1) contains 20 November 2019, 30 December 2019 and 30 December 2020 sowing dates, while the second mega environment (ME2) contains 20 November 2020. The best performing genotypes under ME1 were Shandaweel 2, Sakh 95 and Mis 2, while the best genotype under ME2 was Giza 171. The rest of genotypes were not belonging to any sector because their performance was lower than average performance of any test environments.

Yan and Fregeau (2018) proposed the GY*T biplot technique to tackle the problem of genotypes evaluation on multiple traits or combining yield with other traits rather than yield solely or trait individually. The GYT biplot analysis represented the 91.83% of the total variation (PC1=82.83% and PC2=9.00%) by plotting the first and second principal components in the exclusive biplot views named as the polygon view (Figure 3) and the average tester coordination (ATC) view (Figure 4). The which-won-where polygon (Figure 3) showed that five perpendicular rays radiating from the origin of polygon distributed the biplot into five sectors, among which only two sectors possessed the yield trait combinations. The first sector comprised ten yield trait combinations viz., GY/DH, GY/DM, GY*GRF, GY*SM, GY*KS., GY*TKW, GY*MSI, GY*RWC, GY*LCC and GY*PC and two genotypes viz., Shandaweel 2 (The winner genotype) and Sakha 95.

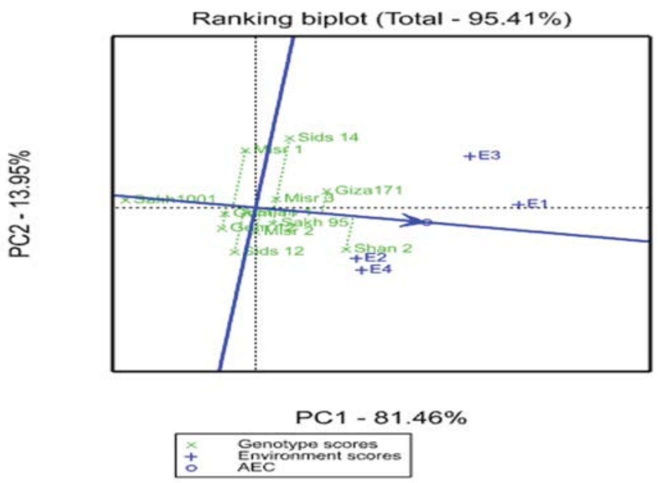

Figure 1. The AEC view of GGE biplot to rank the genotypes based on grain yield data across all environments

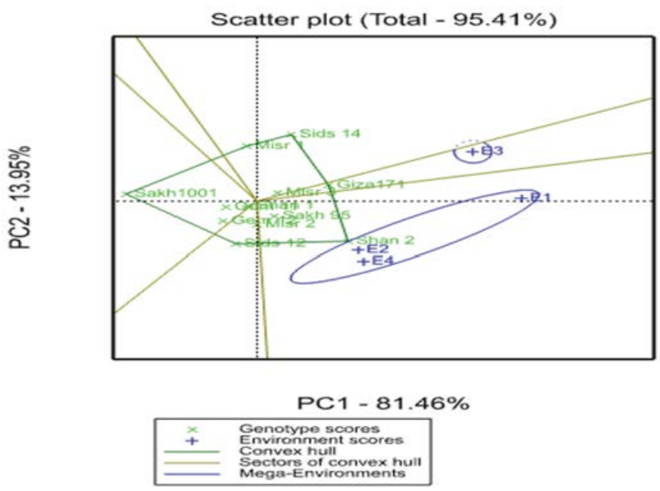

Figure 2. Which-won-where polygon of GGE biplot viewing omega environments and genotypes profile for the test environments

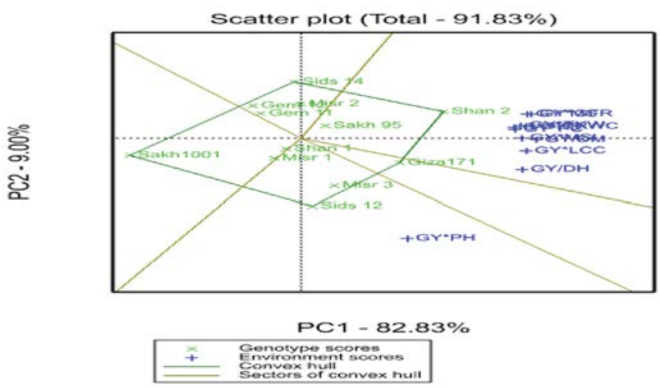

Figure 3. The which-won-where view of the GY*T biplot of genotypes by yield*trait (GYT) to highlight genotypes with outstanding profiles based on all environments

The second sector comprised only yield trait combination GY/PH and four cultivars viz., Sids 12 (The winner genotype), Misr 3, Misr 1 and Shandaweel 1. In contrast, the remaining genotypes not had any yield trait combinations, implying that these genotypes were the poor performer of studied traits in combination to grain yield as compared to rest of genotypes. The mean superiority index overall yield*trait combinations and the ATC view of GYT biplot presented in Table 12 and Figure 4, indicated that the better ranked genotypes regarding the average of all the yield traits combinations were Shandaweel 2, Giza 171, Misr 3, Sakha 95 and Sids 12 with positive mean superiority index of 1.62, 1.17, 0.45,0.25 and 0.20, respectively, and they were plotted at the right side of the double head arrow on the ATA axis. In contrast, the poorer genotype based on its performance regarding the average of all the yield traits combinations were Misr 2, Sids 14, Shandaweel 1, Misr 1, Gemmiza 11, Gemmiza 12 and Sakha 1001 with mean superiority index of -0.04, -0.14, -0.16, -0.28, -0.51, -0.60 and -1.97, respectively, and they were plotted at the left side of the double head arrow on the ATA axis. Among these genotypes, Shandaweel 2 was at the top position followed by Giza 171 with the highest mean superiority index of 1.62 and 1.17, respectively, which had the potential to produce maximum grain yield at the expense of studied traits and signified ideotypes of the testing panel of genotypes to be selected on the basis of breeding goal.

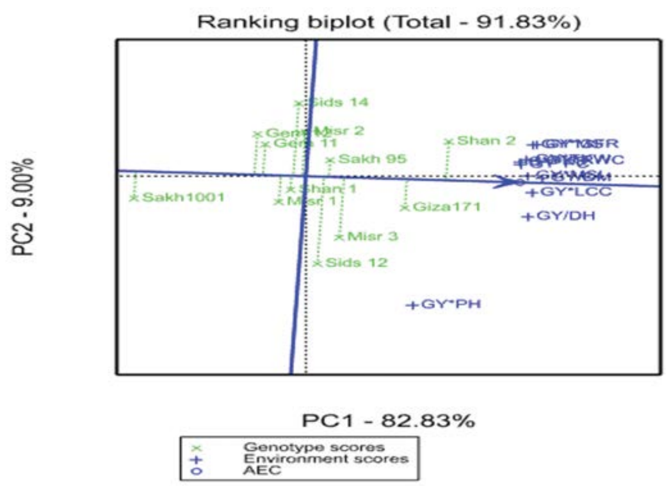

Figure 4. The average tester coordination (ATC) view biplot to rank genotypes based on multiple traits

Table 12. Ranks of the studied genotypes based on superiority index (SI) overall the test environments

Genotype	GY/ DH	GY/ DM	GY* GFR	GY/ PH	GY* SM	GY* TKW	GY* KS	GY* MSI	GY* RWC	GY* LCC	GY* PC	SI
Shand 1	-0.13	-0.21	0.30	-0.27	0.23	0.18	-0.57	-0.66	-0.47	-0.31	0.18	-0.16
Shand 2	1.52	1.78	0.16	2.03	1.83	1.87	1.48	2.19	1.87	1.59	1.48	1.62
Sids 12	0.73	0.28	1.49	-0.23	-0.38	0.23	-0.14	0.01	-0.08	0.94	-0.69	0.20
Sids 14	-0.76	-0.20	-1.18	0.25	0.50	-0.07	0.41	-0.57	0.42	-0.20	-0.14	-0.14
Misr 1	-0.53	-0.38	0.57	-0.39	-0.41	-0.30	-0.43	-0.71	-0.23	-0.56	0.32	-0.28
Misr 2	-0.56	-0.17	-0.76	0.10	0.12	1.00	-0.51	0.26	-0.07	0.00	0.20	-0.04
Misr 3	0.72	0.37	1.36	0.02	0.15	0.38	0.25	0.73	0.30	0.23	0.38	0.45
Giza 171	1.43	1.21	1.21	1.10	1.03	0.33	1.74	1.01	1.23	1.01	1.60	1.17
Gemm 11	-0.28	-0.48	-1.10	-0.64	-0.69	-0.86	0.06	-0.04	-0.77	-0.58	-0.21	-0.51
Gemm12	-0.50	-0.40	-1.19	-0.30	-0.62	-0.65	-0.28	-0.77	-0.69	-0.73	-0.52	-0.60
Sakha 95	0.35	0.49	-0.31	0.46	0.45	0.10	0.14	0.18	0.51	0.76	-0.36	0.25
Sakha 1001	-1.99	-2.29	-0.56	-2.15	-2.21	-2.21	-2.16	-1.64	-2.03	-2.15	-2.24	-1.97

DH: number of days to heading, DM: number of days to maturity, GFR: grain filling rate, PH: plant height, SM: number of spikes/m^2, KS: number of kernels/spike, TKW: thousand kernel weight, MSI: membrane stability index (%), RWC: relative water content (%), LCC: leaf chlorophyll content. and PC: grain protein content (%)

DISCUSSION

The highly significant differences between seasons for all studied traits (Table 3) can be attributed to the rise in temperature of the second season compared to the first (Table 1). Late sowing (terminal heat stress) significantly decreased all studied traits in all cultivars, except grain protein content (Table 3). The significant reduction of days to heading and maturity under late sowing compared to normal sowing date may be due to the decrease in the duration of development phase, as a result of rising temperature at late planting (Abdelkhalik et al., 2021; Shenoda et al., 2021). Delaying planting decreased grain filling rate due to the high temperature on grain production rate (Feltaous et al., 2020; Abdelkhalik et al., 2021). Decrease in plant height under late sowing conditions might have occurred due to higher temperature during growing period that stops vegetative development and shortens the size of the organs. Late sown wheat is usually subjected to extreme low temperature at germination stage, which resulting in poor germination, as well as very poor tillering capacity (Farooq et al., 2008). The reduced number of kernels/spike in the current study could be attributed to low floral fertility, associated with temperature increases during the booting and anthesis stage. Heat stress during anthesis to maturity (GS3) mainly affects assimilate availability, photo-synthate translocation to the grain and starch synthesis and deposition in the developing grain, resulting in a lower kernel weight (Acevedo et al., 2002). Significant reduction in grain yield under late sowing compared to normal sowing (Table 3) may be due to the terminal heat stress during reproductive phases which leads to decrease in number of spikes/m^2, number of kernels/spike, thousand kernel weight and grain filling rate. Similar findings were found by Aglan et al. (2020), Abdelkhalik et al. (2021) and Ahmed (2021). Decrease membrane stability index under late planting could be attributed to cell membrane integrity damage caused by high temperatures (Shaukat et al., 2021). Decreasing in water relative content due to late sowing (heat stress) was reported by Shaukat et al. (2021). The significant loss of chlorophyll under late sowing in leaves occurs due to rapid breakdown of chlorophyll when photosynthetic mechanisms undergo complete destruction under heat stress (Jespersen et al., 2016). Delaying sowing increased grain protein content percentage. Heat stress during grain filling affects the grain protein content through reduction in starch deposition (Wardlaw et al., 2002). The significant differences between genotypes for all traits (Table 3) might be attributed to their genetic diversity and indicated that the differences among genotypes were sufficient to provide a scope to characterize the effect of terminal heat stress. The significant interaction between seasons and sowing dates for all traits, except number of kernels/ pike (Table 4 and 5) suggest that the agro ecological conditions of the sowing dates were extremely different and accounted for most of the traits variation. The significant variance component for interaction between seasons and genotypes (Table 6) suggests a different ranking of genotypes across sowing dates under different seasons. The interaction between genotypes and sowing dates was significant or highly significant for all traits except plant height (Tables 7), suggesting that performance and ranking of genotypes differed from one sowing date to another. The differences between genotypes in all studied traits might be attributed to their genetic variability. Results presented in Table 7 showed that values of all traits for all genotypes (as a mean of two seasons) decreased under late sowing compared to recommended sowing date. These findings are in accordance with those obtained by Feltaous et al. (2020). In the present study, some genotypes performed well under normal sowing but not under the late sowing date (terminal heat stress) and vice-versa, while some of the genotypes performed well under both sowing dates (Table 7). Results in Table 7 show that Shandaweel 2, followed by Giza 171 and Sids 14 performed better than the rest of genotypes for grain yield under the recommended sown conditions. On the other side, Shandaweel 2 outperformed other genotypes under the late sowing. These results suggested that genotype Shandaweel 2 had the best performance under normal and late sowing conditions. The significant increase for Shandaweel 2 than other genotype may be due to increase in GFR, SM, MSI and RWC under different environments. The interaction between season, date and genotypes was significant for all studied traits, except for DM, MSI, RWC and PC (Table 7), suggesting a different ranking of genotypes across seasons and sowing dates. Data of heat susceptibility index (Table 10) indicate that the genotypes Sids 12, Misr 2, Sakah 1001, Gemmiza 12, Sakha 95, Gemmiza 11 Shandaweel 1 and Shandaweel 2 can be considered as heat tolerant genotypes. Four of these genotypes which showed HSI<1, such as Sids 12, Misr 2, Sakha 95, and Shandaweel 2 also had the highest grain yield and the best performance under heat stress conditions. On the other side, Sids 14, Misr 1, Giza 171 and Misr 3 can be labeled as heat sensitive cultivars and they recorded the maximum reduction for grain yield under late sowing. In the present study, most of heat tolerant genotypes showed higher MSI, RWC and LCC under late sowing, suggesting that these traits can be used as selection criteria for heat stress tolerance in wheat. Similar results were found by Shaukat et al. (2021) and Choudhary et al. (2020). Positive significant correlation between grain yield and: DH, DM, GRF, PH, SM, MSI and LCC were found under late sowing. Furthermore, positive and insignificant correlations were observed between grain yield and KS, TKW, RWC and PC. Similar results were reported by Feltaous et al. (2020); Ahmed (2021) and Shaukat et al. (2021). Yield is associated with leaf chlorophyll content during grain filling period (Reynolds and Trethowan, 2007). An ideal genotype should have both high mean yield performance and high stability across environments (Kaya et al., 2006; Yan and Tinker, 2006). Concerning GGE ranking biplot (Figure 1), the length of the average environment vector was sufficient to select genotypes based on yield performances. Genotypes with above-average means (i.e., Shandaweel 2, Giza 171, Sakh 95, Misr 3, Mis 2 and Sids 14) could be selected, whereas the rest were discarded. On the other hand, in addition to genotype yield mean, genotypic stability is quite crucial. A longer projection to the AEC ordinate, regardless of the direction, represents a greater tendency of the GEI of a genotype, which means it that this genotype is more variable and less stable across environments or vice versa. For instance, genotypes Shandaweel 2, Giza 171, Sakh 95, Misr 3 and Misr 2 were more stable as well as high yielding. Conversely, Sids 14 was more variable, but high yielding. The polygon view of GGE biplot (Figure 2) showed that Shandaweel 2, Sakh 95 and Mis 2 genotypes were suitable for planting under normal and late sowing, while cultivar Giza 171 was suitable for planting under normal conditions. The rest of genotypes were not belonging to any sector because, their performance was lower than average performance of any test environment. The results of the GYT polygon view in Figure 3 showed that 5 genotypes were the polygon vertex, among which Shandaweel 2 was the best genotype for main yield components: DH, DM, GRF, SM, KS, TKW, MSI, RWC, LCC and PC while cultivar Sids 12 was coupled with PH. In contrast, the remaining three vertex genotypes Giza 171, Sids 14 and Sakha 1001 were winners of respective sectors, but did not possess the desired level of multiple traits to be selected as ideotype. The ATC view is the most unique feature of GYT biplot as it displays the ranks of contesting genotypes based on strengths and weaknesses of each genotype (Yan et al. 2019). Results of the ATC biplot and superiority index (Figure 4 and Table 12) grouped 5 genotypes, i.e., Shandaweel 2, Giza 171, Misr 3, Sakha 95 and Sids 12 as superior and 7 genotypes: Misr 2, Sids 14, Shandaweel 1, Misr 1, Gemmiza 11, Gemmiza 12 and Sakha 1001 as inferior. Among these genotypes, Shandaweel 2 and Giza 171 had the best traits profile which also depicted by GYT Table 12 that all the yield combinations of these genotypes had positive values and they were stable. In contrast, the seven inferior cultivars had the poor trait profile when assessed in combination with yield, hence could be they rejected on the basis of multiple traits.

CONCLUSION

Late sowing (heat stress) had a negative impact on all studied traits, except protein content. The genotypes Sids 12, Misr 2, Sakha 95, and Shandaweel 2 showed HSI<1 and had the highest grain yield under late sowing date. Therefore, they can be labeled as heat tolerant genotypes. Moreover, Shandaweel 2 was stable and outperformed the genotypes under both sowing dates. On the other hand, Sids 14, Misr 1, Giza 171 and Misr 3 had the maximum reduction in grain yield under late sowing and they can be considered as heat sensitive cultivars. GGE biplot analysis revealed that Shandaweel 2 was the an ideal genotype in terms of yielding ability and stability. The GYT biplot analysis showed that genotypes Shandaweel 2 and Giza 171 had the best traits profile. This study recommended release of new wheat genotype Shandaweel 2 as new cultivar and use it to develop heat-tolerant bread wheat genotypes in breeding programs.

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